

THE SPACE FORTRESS GAME *

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Space Fortress was developed in the Cognitive Psychophysiology Laboratory as an experimental task for the study of complex skill and its acquisition. The development process was long and iterative. The first step was the development of a computer-controlled task with game-like qualities. This was followed by a series of modifications and additions that were incorporated into the game and evaluated. The goals were (1) to create a complex task that is representative of real-life tasks, (2) to incorporate dimensions of difficulty that are of interest based on existing research on skill and its acquisition, and (3) to keep the task interesting and challenging for the subjects during extended practice. Earlier versions of the game were used in previous experiments (Mané et al. 1983a; 1983b; 1984; Mané 1984). The version of the game that is described below was used by all the participants of the Learning Strategies project.

The rules of the Space Fortress game

The object of the Space Fortress game is to shoot missiles at and destroy a space fortress. Missiles are fired from a spaceship whose movement is controlled by the subject. In addition to destroying the fortress, the subject must protect his ship against damage. As he plays the game the subject faces a TV monitor. The layout of this screen is presented in fig. 1. The various components represented in fig. 1 are described below.

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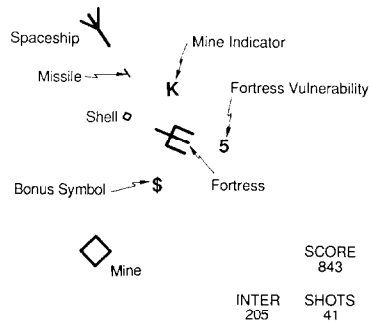


Fig. 1.

Sound effects are presented to the subject through headphones. These sounds represent the firing of missiles and the explosion of various objects. The ship is controlled and missiles are fired by means of a joystick and trigger manipulated by the subject's right hand. Forward movement of the stick causes the spaceship to accelerate. Lateral movements cause the ship to rotate. Because the ship flies in a frictionless environment, it continues to fly in the direction in which it is pointing unless it is rotated and thrust is applied. When the path of the ship brings it to the edge of the screen, the ship disappears into 'hyper-space' and immediately reappears on the opposite side of the screen.

The subject's task is to destroy the fortress located in the center of the display. Before he can destroy the fortress, the subject must make it vulnerable. This is accomplished by shooting the fortress ten times with at least 250 msec between each missile. Once the fortress is vulnerable it can be destroyed with a burst of two shots fired with an interval of less than 250 msec. The number of hits scored against the fortress is called the index of vulnerability, and is displayed next to the fortress at all times.

In the course of destroying the fortress, the subject has to overcome a number of obstacles. First, the fortress defends itself against the ship. It does this by rotating to face the ship, and then trailing the ship's movements while firing shells at it. In addition, the fortress is protected by mines which emerge on the screen periodically and chase the subject's ship. If the subject does not take action against the mines they will run into the ship and damage it. There are two types of mines: 'friend' and 'foe'. A letter presented in the center of the screen when

the mine appears indicates which type of mine it is. (Prior to each block of play, the subject is told which letters will be used to identify foe mines.) If the mine is a foe, the subject has to arm his ship with the appropriate weapon system. The subject switches weapon systems by pressing a button twice, with an interval of 250–400 msec between the two presses. The mine can then be eliminated by a missile. If the mine is a friend, the weapon system does not need to be switched. When hit by a missile a friend mine is ‘energized’, that is, the mine changes direction and runs into the fortress, scoring a hit against it. If the subject fails to destroy a foe mine or to energize a friend mine within 10 seconds, the mine disappears from the screen. The interval between the disappearance of one mine and the appearance of the next is 4 seconds, during which time the subject can fire at the fortress. While mines are present on the screen, missiles fired by the subject at the fortress have no effect.

If mines or fortress shells hit the ship it is damaged. When the ship is damaged for the fourth time it is destroyed. Destruction of the ship or the fortress resets the game to its starting configuration. Throughout the game the subject’s score is computed and displayed. Points are added when the subject hits one of the hostile elements and deducted when the ship is damaged or destroyed. Table 1 contains the number of points added or subtracted upon each event.

At the start of the game the subject is given a supply of 100 missiles from which he draws when firing at hostile elements. The number of missiles remaining in his arsenal is displayed in the lower right-hand corner of the screen. Once out of missiles the subject can continue to shoot, but 3 points are subtracted from his score for every missile

Table 1
Computation of the total game score.

Points are added when	Points are subtracted when
Fortress is hit (+4)	Ship is damaged (–50)
Fortress is destroyed (+100)	Ship is destroyed (–100)
Bonus points are earned (+100)	Shots are fired when missiles are not available (–3/shot)
Foe mine is killed (+30)	
Friend mine is energized (+20)	

expended. However, opportunities to obtain more missiles are provided. A sequence of symbols is continually presented beneath the fortress. One of the symbols, the dollar sign, appears twice in a row whenever it appears. The second appearance of the dollar sign is the subject's opportunity to obtain more resources. By pressing one of two buttons while the second dollar sign remains on the screen, he can receive 100 points or 50 more missiles.

The Space Fortress computer program

The shape and form of the Space Fortress game is defined by a set of 50 parameters which determine every aspect of the task. A few examples of these parameters are the speed of the hostile elements, the number of letters constituting the memory set for the identification of foe mines, and the time allowed before the fortress aims at and begins to fire on the subject's ship. Parameters can be modified between blocks or even as the subject plays the game. This allows the experimenters easy manipulation of various dimensions of the game.

Evaluation of performance is presented to the subject in the form of a game score – the sum of the point received for damage to hostile elements minus the penalties for damage to the spaceship (see table 1). This score is a measure of overall proficiency. However, it is not the only dependent variable recorded and evaluated in the Learning Strategies studies. An array of 150 data variables is collected which can be used to describe many aspects of subject behavior during every block of training. These variables describe stick movements made by the subject, ship movements, fortress movements, the efficiency with which the subject used the buttons for switching weapon systems and choosing resources, the number and fate of missiles fired, the number of fortress and mine destructions, the amount and source of damage to the ship, the subject's success with the timing aspects of the game, the subject's speed in responding to new events, and many other aspects of performance. This wealth of data allows the experimenter to perform a fine-grained analysis of his subjects' progress in the acquisition of game skills.

Ability assessment

Past experience with the Space Fortress game showed that some subjects find the task so difficult that they have to be removed from the experiment. To reduce costs associated with running such subjects, and more importantly, to gauge the subjects' initial level of expertise, a screening task was administered to all subjects. An aiming drill was chosen to serve as the screening task because pilot work and previous research (Mané et al. 1984) indicated that the level of success in this task has a positive correlation (of 0.44, $p < 0.01$) with eventual success in the game. Only the spaceship and mines are involved in the aiming task. The spaceship is stationary in the center of the screen, but will rotate when the subject manipulates the stick. Mines appear one at a time in one of 24 locations on the screen. The mine is stationary and disappears when hit by a missile or when 10 seconds have elapsed since its appearance. One second later another mine appears on the screen. By rotating to aim at the mine and pressing the trigger to fire a missile, the subject destroys the mine. To qualify for the experiment subjects had to destroy at least 31 mines in a 2 minute block. Subjects who exceeded this criterion and were admitted into the study were then stratified into five levels of expertise based on their best score in the three screening blocks.

The Space Fortress game as a research tool

Space Fortress is an exciting game. Many of the subjects who participated in the experiment expressed enjoyment in the game; the challenge it presents kept them motivated throughout the experiment. However, the game-like qualities of the task should not divert attention from the fact that Space Fortress is a sophisticated research tool. In playing Space Fortress, subjects provided data on the acquisition of skill in a complex but well controlled environment.

The skills involved in mastering the game are multidimensional. Perceptual, cognitive, and motor skills are required of the player, as well as specific knowledge of the rules and game strategy. This level of complexity is unusual in an experimental setting. Most research in the area of skill acquisition has been conducted with simpler paradigms and shorter training periods (e.g., Adams and Reynolds 1954).

One difficulty in the design of a task such as Space Fortress is the danger that one feature or property of the game will emerge that dominates the task to such an extent that it becomes the only component of importance, in effect simplifying the task. Or it may be possible to find a loophole in the task which allows one to achieve the goal of the game without learning how to perform the complex skill. Although in real life there may be nothing wrong in achieving a goal in this way, in an experimental paradigm it is important to maintain the game's intended complexity in order to allow the investigation of complex skill. Previous versions of the Space Fortress suffered from such difficulties. These problems have been addressed, and in order to score optimally in the present versions of the game the subject must attend to all game elements. We believe that the large number and variety of skills involved in playing the game, together with the large amount of previous research into the task, make Space Fortress an excellent candidate task for studies into the acquisition of skill in complex perceptual-motor environments.

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